Proceedings of the 16th International Congress on Acoustics / 135th Acoustical Society of America Meeting
Seattle, WA, June 20-26, 1998 pp 1873-1874

Structural Vibration Mode Imaging Using Photorefractive Holography

K. L. Telschow and V. A. Deason

Idaho National Engineering and Environmental Laboratory
Lockheed Martin Idaho Technologies Co., Idaho Falls, ID 83415-2209, U.S.A.

Abstract: Photorefractive processing of optical interference offers a noncontacting optical method for vibration detection that forms an optical "lock-in" amplifier. This paper describes the ability of this photorefractive method, when coupled with laser thermoelastic heating, to provide an all-optical imaging vibration measurement suitable for intelligent sensing.

PHOTOREFRACTIVE OPTICAL VIBRATION DETECTION

Many optical techniques have been developed for performing noncontacting vibration measurements; most of these methods have similar sensitivities and are based on passive optical interferometry (1). Adaptive interferometry, which uses the photorefractive effect in optically nonlinear materials, offers a potentially powerful method for real-time optical image processing and automatic correction for environmental effects. Photorefractivity employs optical excitation and transport of charge carriers to produce a hologram of an interference pattern inside the nonlinear optical material (2). The hologram is a direct measure of the phase information impressed onto the optical object beam by the vibrating surface and stores simultaneous phase information from all the surface points on the vibrating specimen. The readout beam intensity response is proportional to the Bessel function of order one, providing a linear output for small amplitudes. Narrow bandwidth detection with flat frequency response can be achieved above the photorefractive response frequency (~100 Hz). Multi-wave mixing with synchronous detection allows direct measurement of both the amplitude and phase of a vibrating surface as a function of the excitation frequency. Minimum detectable displacement amplitudes of a few picometers have been demonstrated for a point measurement (3), allowing for the direct measurement of very small vibrational motions. Both specularly and diffusely reflecting surfaces can be accommodated.

Figure 1 shows the experimental setup for optical detection of a vibrating plate. A diode-pumped Nd:YAG laser source (532 nm, 200 mW) is split into object and reference beams. The excited vibrational modes of the plate phase modulate the object beam. The reference beam is phase modulated by an electro-optic modulator (EOM). The object and reference beams are then combined inside a bismuth silicon oxide (BSO) photorefractive crystal. A four-wave mixing configuration is shown for readout but other approaches are also useful (4). The reference beam is reflected back into the crystal along a counter-propagating path that matches the Bragg angle of the photorefractive grating in the medium. The resulting scattered wave is then directed at the beamsplitter to the photodetector.

Vibration measurement can be totally noncontacting if an optical excitation source is used. Laser light striking a solid heats it, producing a strain that is modulated in the same manner as the laser light is modulated, i.e. chopped. In addition to being noncontacting, optical excitation offers significant potential for selectively exciting certain vibrational modes by altering the region of excitation to enhance the response of one vibrational mode over another. A continuous wave, 700 mW average power, diode laser was used as indicated in Figure 1. An acousto-optic modulator chopped the excitation source, producing a modulation component at the frequency of interest. The chopping was synchronized with the electro-optic modulator as the measurement frequency was swept through several vibrational modes. Figure 2 shows the effect of laser excitation at three points around the plate. Several plate modes are depicted in Figure 2, one with nodal lines traversing across the plate from corner to corner at 1.5 kHz, one with a vertical nodal line from the top to the bottom corners, and two parallel

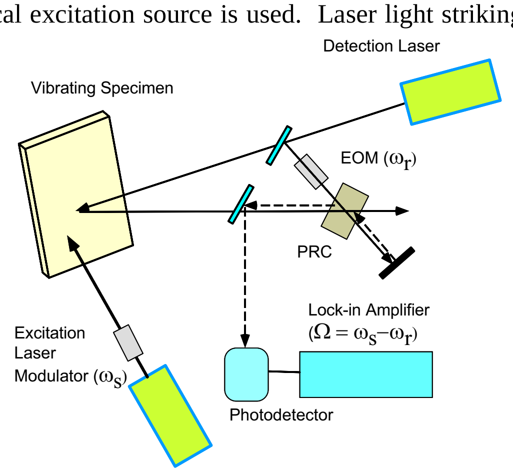


Figure 1. Photorefractive detection of vibration using four-wave mixing. EOM is “electro-optic modulator”, PRC is “photorefractive crystal”.

lines closer to the left and right corners at 2.4 kHz. The optical source position determines the response: excitation at Point A selected against the 1.5 kHz mode, B selected against the 2.4 kHz mode, and C selected against both modes. Greater excitation occurs when the optical excitation spatial profile matches the vibrational mode profile.

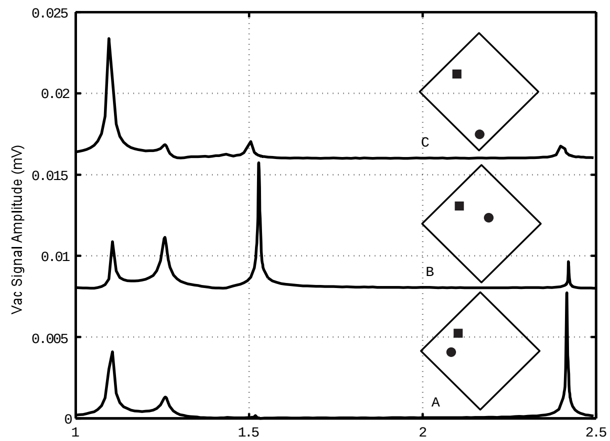
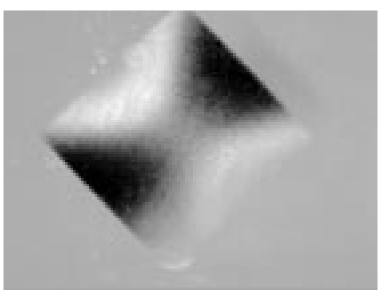


Figure 2. Vibrational response showing the source laser excitation (circles) positions A, B, C and the detection spot (square).

VIBRATION IMAGING

Since the optical interference and the photorefractive effect occur throughout the photorefractive material, the single point detection method described above can be generalized to form an image of the vibration over the surface of the plate. The output beam intensity from the detection process can be measured directly by a CCD camera. Each pixel records the local intensity at a point on the specimen and produces an output proportional to that point's displacement. This capability for imaging is a significant enhancement of the photorefractive measurement method, compared with other optical interferometric methods, as it provides real-time full-field measurement at virtually any vibration frequency. Figure 3 shows images of the modes at 1.5 and 2.4 kHz. The nodal lines are clearly defined, and the relative phases of the vibration displacements are indicated by the light and dark areas. The entire mode pattern can be made to switch from light to dark by varying the offset frequency between the object and reference excitations. This provides a powerful tool for visual mode searching and suggests processing methods that can be employed to enhance the detectability of specific modes. The minimum detectable displacement in the imaging mode (~1 nm) is much larger than for the point detection method as no post electronic processing was performed. The output intensity is directly proportional to the amplitude of the vibration being measured for amplitudes that are small relative to the optical wavelength. The method is capable of flat frequency response over a wide range above the cutoff of the photorefractive effect and is applicable to rough diffusely reflecting surfaces. Furthermore, the output is easily recorded with standard CCD camera technology, which allows conventional video processing, feedback, and control to be implemented for smart sensing systems.



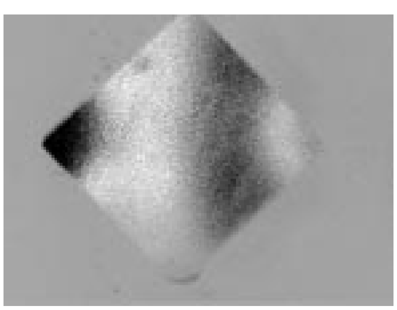


Figure 3. Images of the vibrational modes at 1.5 kHz (top) and 2.4 kHz (bottom).

ACKNOWLEDGMENTS

The authors thank Rob Schley and Kirk Ricks for help in obtaining the laboratory measurements. This work was supported through the INEEL Laboratory Directed Research & Development program under DOE Idaho Operations Office Contract DE-AC07-94ID13223.

REFERENCES

1. Wagner, J. W. *Optical Detection of Ultrasound,* Physical Acoustics, Vol. XIX, Eds. Thurston, R. N., and Pierce, A. D., (Academic Press, New York, 1990) Chp. 5.
2. Yeh, P. *Introduction to Photorefractive Nonlinear Optics,* (John Wiley, New York, 1993).
3. Hale, T. C. and Telschow, K. L. *Appl. Phys. Lett*. **69,** 2632 (1996).
4. Hale, T. C., Telschow, K. L. and Deason, V. A. *Applied Optics*, **36**(31), 8248 (1997).